

1. THE CONTEXT FOR A HAZARD ANALYSIS OF COMMERCIAL SPACE ACTIVITIES

1.1 POLICY AND MARKET CONTEXT

A new set of realities, shaping space activities worldwide, must be considered in order to provide the context for the nature, scope and thrust of commercial space efforts in the US. An extensive set of recent Congressional legislation, studies and reports⁽¹⁻⁸⁾ has documented the rapidly changing climate for international cooperation and competition in space activities and the need for greater political and economic flexibility in providing access to and services for space exploration and exploitation, if the US is to maintain its leadership in space. The arena of space technology, infrastructure development and new space applications has expanded in recent years to include more developed and third world nations.^(2,8) In 1986 alone, the USSR had 91 successful space launches vs. the US with 6 and 2 each for China, Japan and ESA (European Space Agency). The US is revising and reshaping its space policy and priorities. These changes are needed if it is to provide the national and international leadership and foster the stability to ensure that, following the initial space exploration and utilization phase, the promise of commercial space development becomes a reality.⁽³⁻⁷⁾ This will enable the US aerospace industry to capitalize on its technical superiority for the benefit of mankind and economic pay-back.

Both Congress and the Administration have proposed, enacted and promoted new space commercialization initiatives, most notably in privatizing remote sensing satellites and promoting the use of commercial expendable launch vehicles (ELV's) and launch services to place both government and commercial satellites into orbit.^(6,7,9)

In May 1983, the President issued a new policy for commercialization of ELV's and in February 1984, by Executive Order 12465 ("Expendable Launch Vehicles in Space"), he designated the Department of Transportation (DOT) as the lead agency to facilitate and encourage commercial ELV activities and to license commercial space operations.

The STS-Challenger disaster and ensuing ELV accidents have severely limited the US access to space and indirectly provided new opportunities and incentives to ELV manufacturers and to commercial payloads and launch services providers.^(7,10) As a result, all government agencies involved in space activities have been instructed to enable, foster and implement the new commercial space policies and laws and to develop the supporting regulatory framework and technology infrastructure for greater private sector participation in space transportation and development efforts.

1.2 REGULATORY CONTEXT FOR COMMERCIAL SPACE OPERATIONS

The Commercial Space Launch Act of October 30, 1984 (Public Law 98-575) (the Act), assigned to the Secretary of Transportation the responsibility for carrying out the Act.⁽⁶⁾ The purpose of this Act is:

(1) to promote economic growth and entrepreneurial activity through utilization of the space environment for peaceful purposes;
(2) to encourage the United States private sector to provide launch vehicles and associated launch services by simplifying and expediting the issue of commercial launch licenses, facilitating and encouraging the use of excess Government-developed space launch capabilities and transferring technology to the private sector ;
(3) to designate an executive department to oversee and coordinate the conduct of commercial launch operations; to issue and transfer commercial launch licenses authorizing such activities; and to protect the public health and safety, safety of property, national security and foreign policy interests of the United States.

In 1984, the Secretary of Transportation created the Office of Commercial Space Transportation (OCST) and delegated to it the Secretary's responsibilities. As stated in Section 8(a)(2) of the Act, the Secretary is charged with prescribing "requirements as are necessary to protect the public health and safety, safety of property, and national security and foreign policy interests of the United States."

To carry out this responsibility, OCST established a program to develop safety and regulatory requirements for commercial space launch license applicants.⁽¹²⁾ The Transportation Systems Center (TSC) is providing technical support to OCST to this end and has been assisting in the development of launch safety requirements based on the Preliminary Hazards Analysis embodied in this report.

However, it must be made clear that the focus of OCST licensing and regulatory activities is primarily on public safety and not on mission success.^(6,12) This unique perspective and mandate for DOT is and will be reflected in the OCST safety research, rule making and licensing activities. DOT will have to regulate not just commercial launch sites and commercial launches, but payloads launched aboard these vehicles. These include retrievable materials processing, re-entry systems, non-government research activities and many other, as yet unforeseen, commercial space systems.

DOT/OCST will also license the construction and operation of new private launch Ranges, as well as any commercial Range Safety services.⁽¹²⁾ OCST will also specify the certification requirements

for Range Safety personnel and launch services providers, that might impact the public safety. Under the Act, DOT must also issue licenses for any launch vehicle or operation on foreign territory by a US citizen or company.

1.3 PURPOSE AND SCOPE OF REPORT: HAZARD ANALYSIS OR RISK ASSESSMENT

This report presents the results of a technical review and analysis of literature and information in the public domain, conducted to identify and evaluate the prospective hazards to the public and the environment, and to assess risk exposure levels associated with commercial space activities. Included in the report is a review of the present status of US space technology and practices (Vol. 1), as they relate to the hazards associated with commercial space missions and their mitigation (Vol. 2). In this analysis, a commercial space mission is comprised of four phases: prelaunch, launch, orbital and re-entry (Table 1-1). For each mission phase the potential classes of hazards which pertain to the people, procedure, equipment, facility and environmental elements are identified.

TABLE 1-1. PHASES OF COMMERCIAL LAUNCH OPERATIONS

| PHASE | PRELAUNCH | LAUNCH | POST-LAUNCH MISSION AND OPERATION | | |
|--|---|--|---|--|--|
| | | | PHASE A ORBIT INSERTION OF PAYLOAD | PHASE B PAYLOAD ON ORBIT OPERATION AND STATION- KEEPING | PHASE C 1. DE-ORBIT AND RE- ENTRY 2. OR: MANEUVER TO HIGH STORAGE ORBIT |
| Representative Hazards or Events | <ul style="list-style-type: none"> • Damage to ELV in transit, storage, assembly and testing • Damage to Launch Facilities and Ground Support Equipment • Hazards to personnel • Environmental Damage | <ul style="list-style-type: none"> • On the pad explosion • Low altitude explosion • Failures of 1st, 2nd or upper stages • Failure of guidance and/or destruct system | <ul style="list-style-type: none"> • Malfunction in any of the boost stages, and/or motors • Malfunction of apogee / perigee kick motor | <ul style="list-style-type: none"> • Collision with debris, or other orbiting satellites • Malfunctions and operational failures | <ul style="list-style-type: none"> • Re-entry Hazards: Natural de-orbit and breakup • Rapid uncontrolled loss of altitude due to solar activity, or failure to maintain orbit • Damage to property or casualties in U.S. & abroad |

These hazards have been identified and evaluated in light of DOT/OCST's mission, based on the review of existing literature and practice of space related risk analyses (Vol.3).

The following definitions will aid the reader with the assimilation of information in this report. An extensive Glossary of terms has been provided (Appendix A) and a discussion of terminology and procedures is given in Chapter 8 (Vol. 3).

An accident is defined as an undesirable event resulting from any phase of commercial ELV launch operations and space activities with the potential to cause injury or death to people, or damage to property.

Risk assessment is the systematic examination of an actual or proposed system or operation, to identify and evaluate potentially hazardous events and their consequences. The principal purpose of such an analysis is to assist policy makers, regulators and managers in deciding on risk avoidance, risk reduction or mitigation strategies. It can lead to either confirming the continued acceptability of a system or operation from the safety point of view, or setting new risk acceptability and regulatory thresholds for the protection of public safety (see Ch. 8, Vol. 3). Although the terms Risk Assessment and Hazard Analysis are both used in this report in nearly synonymous fashion, the latter is part of the former. There are other closely related terms used in the literature in similar contexts: "Hazard" is often interchanged with "Risk", and "Analysis" for "Assessment", thus giving four common usage expressions, namely: risk assessment, risk analysis, hazard assessment and hazard analysis.

i) An Analysis is typically a technical procedure following an established pattern;

ii) An Assessment is the consideration of the results of analysis in a wider context to determine the significance of the analytical findings;

iii) A Hazard is considered to be an existing property, condition, or situation, which has the potential to cause harm. For example, liquid hydrogen used as a rocket propellant is a hazard because of its chemical nature, and intrinsic flammability and explosiveness.

iv) Risk is related to both the consequences of an accident (i.e., hazard potential being realized and causing harm) and its likelihood of occurrence (Ch. 8, Vol.3). Risk is mathematically expressed as the product of the probability of an accident and the magnitude of its consequence. Thus, the risk from a liquid hydrogen tank is the product of the probability that its containment will fail and the magnitude of the resulting explosion

and/or fire damage. Hence, people and property may be considered "at risk" from a nearby hazard.

v) An Accident occurs when the hazard potential for damage is activated by a stimulus and results in damage to a given system, component or operation, or in injury to people. Other operational and technical definitions for terms used throughout the report are given in the Glossary (Appendix A).

It must be kept in mind that a system or operation is considered to be "safe" when its risks are deemed economically, socially and politically acceptable, based on prevailing standards. These issues will be discussed and illustrated in detail in Vol. 3.

1.4 APPROACH TO HAZARD ANALYSIS FOR COMMERCIAL SPACE OPERATIONS

For over two decades, the US Government has been one of the world leaders in the development and exploration of outer space. In this role, the Government mission agencies (NASA and DOD) have developed and successfully implemented launch safety requirements in support of a wide variety of space missions (see Chs. 2 and 4 of Vol.1). Launch safety requirements have been established for both unmanned and manned space systems and operations, as well as for integration of specific payloads. As such, the standards presently in use at Government Ranges have evolved not only out of the need to protect the public safety and property, but also from the need to protect launch site personnel, facilities and on board astronauts; to ensure mission success; to evaluate launch vehicle performance; and to provide research results that would assist in expanding the national space exploration effort.

Since the only currently available launch sites are National Ranges owned and operated by US Government agencies (DOD and NASA as first parties), the basic launch and system safety regulations now in place at these facilities will probably continue to be observed in the near future by any commercial launch vehicle provider or operator that requires access to and use of Government launch facilities (second party). Cost, access and time constraints may influence the viability of commercial launch operations on these Ranges, while vehicle reliability and safety will remain major concerns. Recognizing this situation, OCST has undertaken an effort to examine ELV safety standards, launch hazards and risk analysis methods to ensure the protection of public safety and property⁽¹²⁾ (third party), as opposed to Government launch facility (first party) and ELV or satellite manufacturers and operators (second party) who enter User Agreements.

As the initial effort in the development of a program to address the safety issues, this report focuses on the identification and evaluation of the safety hazards associated with ELV's and their

launch operations from established and available Government Ranges as well as new launch sites that may be developed and operated in the future by commercial entities, or in partnership with states and federal entities.

Protecting the public health and safety as stated in the Act, requires that safety regulations be directed at preventing the occurrence of potentially hazardous accidents and at minimizing or mitigating the consequences of hazardous events. This will be accomplished by employing system safety concepts and risk assessment methodology to identify and resolve prospective safety hazards. The first step in applying system safety concepts is to define the commercial space launch hazards (preliminary hazard analysis, PHA). With the hazards defined, it is then possible to identify and rank those associated with each specific commercial space launch. Only after the hazards have been identified and satisfactorily assessed, will the goal of providing the public with the highest degree of safety practical have been accomplished. For the preliminary hazard analysis (PHA) presented in this report (Vol. 2), the operational commercial space launch phases have been defined as follows:

1. Prelaunch;
2. Launch;
3. Orbit;
4. Re-entry

For each of these life and operability phases of the commercial space launch process, it is possible to identify the generic classes of hazards that are associated with each phase (see Table 1-1) and to define appropriate regulatory oversight. To identify these hazards, a clear understanding of the system and its operation is necessary, as well as an analysis of the relevant accident history for specific launch systems and subsystems during each phase of launch operation. An analysis of previous accidents is necessary, but not sufficient, for the identification of prospective hazards, since both vehicle configurations (see Ch. 3, Vol. 1) and launch and Range Safety procedures (see Ch. 2, Vol. 1) have improved with time. In 30 years of Government space launch activities and ELV operations to date, both the military and civilian sectors have had an excellent safety record and there have been no major accidents with reported public injuries. Therefore, the data base from which the hazards can be identified is limited, and known to be incomplete, with rare identical failures (see Ch. 3). Furthermore, an examination of historical launch data can provide only a tentative list of probable causes and likely accident scenarios and may be incorrect for the purpose of projecting future performance. Special statistical methods may have to be used to account for "learning" from past failures in order to avoid repeating them (see Ch. 9, Vol. 3).⁽⁷⁾ Previous government ELV and space missions will, however, have to be used to generate a set of representative, expected, and projected commercial space launch missions (see Ch. 10, Vol. 3). This

approach will allow us to examine and evaluate generic hazards associated with commercial space ELV missions (see Chs. 5-7, Vol.2).

1.5 OVERVIEW OF THE REPORT ORGANIZATION

This report is intended to inform and educate a broad readership on the generic sources and nature of hazards associated with space launch activities. Therefore, it is intended to provide both the necessary technical background and the specific hazard analysis methodology, in order to enable a non-technical reader to understand and appreciate the variety of technical issues involved.

Volume 1: Space Transportation Operations provides the background on Range Operations (Ch. 2), current Expendable Launch Vehicles (Ch. 3), and Space Launch and Orbital Missions (Ch. 4). Chapter 2 describes the Range Safety Control systems in place and established practices at the National Ranges. Chapter 3 introduces the basic technology, and typical proven and proposed configurations of ELV's likely to be used for commercial space missions in the near future.

The historical reliability based on launch success/failure statistics for the major classes of operational ELV's in the US are also presented in Chapter 3. Chapter 4 describes the space launch and orbital operational phases.

Volume 2: Space Transportation Hazards introduces the generic classes of hazards associated with the use of these ELV's in space launch operations. Chapter 5 discusses fires, explosions, toxic vapor clouds and debris impacts.

A relative risk context is provided in Chapter 5 to enable the reader to judge launch hazards by comparison with other common industrial and transportation hazards. Chapter 6 discusses orbital collision hazards to satellites in low and geosynchronous Earth orbits. Chapter 7 reviews and evaluates those hazards to people and property associated with both controlled, and uncontrolled re-entry of space objects.

Volume 3: Space Transportation Risk Analysis deals with the analytical tools available to assess public risks (Ch.8), the modeling and application of such tools to space operations (Ch.9) and illustrates the specific risks associated with commercial ELV launches in the near future (Ch.10).

Since DOT/OCST will sponsor and perform risk assessment/risk management research to support commercial space launch licensing reviews and awards, Chapter 8 defines and introduces the standard methods of Risk Assessment. Chapter 9 reviews the published technical risk assessments conducted for selected space applications, focusing specifically on when, how and why such risk

studies were conducted and on the software tools available for this purpose.

Finally, in Chapter 10, an illustration of risk analysis is provided for representative ELV launch/mission scenarios which indicates how the public risk exposure from commercial space activities may be estimated, both with and without Range Safety controls in place. Also, a conceptual risk assessment and acceptability matrix is provided for comparing public risk levels associated with each phase of space launch operations. The benefits of Range Safety control systems and practices now enforced at Government Ranges as the key safeguards to manage and minimize the public risk exposure from future space activities to "acceptable" levels are made clear in Chapter 10.

REFERENCES TO CHAPTER 1

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(c) "Commercial Space Transportation; Licensing Regulations; Final Rule," April 4, 1988 (FR 53, No. 64, p. 11004 et seq.)